Phase I Project Summary

Firm: CFD Research Corporation (CFDRC)
Contract Number: NNX13CM16P
Project Title: Radiation-hardened, Memristor-based Memory for Extreme Environments

Identification and Significance of Innovation:
NASA exploration flight projects, robotic precursors, and technology demonstrators that are designed to operate beyond low-earth orbit require avionic systems that can endure the extreme temperature and radiation environments of space. The lack of low-cost Radiation-Hardened (RH) Non-Volatile Memory (NVM) continues to be a severely limiting factor. Present hardening solutions often rely on inefficient techniques based on redundancy which results in a penalty in performance, weight, and size. Moreover, most aerospace applications preclude the use of moving parts, such as the one in a hard disk. Currently used flash-based memories are vulnerable to ionizing radiation and face significant concerns related to scalability, endurance, and program/erase speeds, in addition to concerns about low temperature reliability. An inherently radiation-hard nonvolatile memory that can achieve high density and operate in extreme temperatures is needed.

Innovations:
(a) Memristor (or Resistive RAM) is a promising technology for next generation non-volatile memory, offering a highly-desirable combination of density, access speed, low power, and radiation-hardness.
(b) First-ever characterization of both chalcogenide-glass (ChG) and transition-metal-oxide memristor technologies under extreme temperatures and radiation environments.
(c) Physics-based memristor device models for design and verification of custom memory circuits for space.

Technical Objectives and Work Plan:
Overall technical objectives of this SBIR effort: (a) characterize performance of candidate memristor technologies in extreme temperatures and radiation environments; and (b) develop advanced models & tools for design, performance assessment, and optimization.

Specific Phase I objectives:
1. Evaluate electrical performance of chalcogenide-glass memristors at extreme/wide-temperatures.
2. Implement memristor-specific models in CFDRC’s simulation software and validate simulation results against experiments.
3. Develop plans for further research and development in Phase II and III, and commercialization of the most promising memristor technology into non-volatile memory.

Work Plan:
1. Add new models within existing drift-diffusion framework in CFDRC’s device-physics simulator for memristor analyses including ion transport and chemical reactions.
2. Fabricate ChG memristors based on Programmable Metallization Cell (basis for commercial CBRAM technology).
3. Perform wide temperature (-230°C to +25°C) electrical characterization of memristors including DC current-voltage measurements and investigate parameter evolution with temperature including V_{set}, V_{reset}, R_{on}, and R_{off}.
4. Perform simulations of memristor behavior and validate against electrical characteristics from ASU. This includes double-hysteresis behavior of I-V curve, internal species distributions (Ag, Ag+), and initial atomistic modeling of filament growth/dissolution responsible for resistive switching in ChG nanoionic devices.

Technical Accomplishments:
All technical objectives of the project were accomplished by the SBIR team. Major achievements include:

- ChG nanoionic memristors based on the Programmable Metallization Cell (PMC) technology were fabricated at ASU. This included device growth, contacting, wirebonding, and packaging for subsequent wide-temperature characterization.
- ChG devices from two different chips/die were tested via low temperature experiments, and repeated resistance switching was observed (i.e. devices were fully operational) at room temperature (control), 250K, 169K, 110K, and 40K.
  - → Characteristics of the resistance switching evolved with temperature.
  - → Successful demonstration of ChG memristor operation across a wide-temperature range (down to 40K or -233 ºC) serves as an important **proof-of-concept** for the applicability of ChG memristors to NASA relevant environments.
- We developed an initial set of models allowing for multi-scale physics description of ChG memristors: *'macroscopic' (drift-diffusion) model* for faster predictions of device/circuit operation, and *'atomistic' model* for atomistic-level fidelity necessary for detailed understanding of such nanoscale device performance.
- Drift-diffusion based ChG memristor simulations were <u>validated against published results</u> [Barnaby 2013] for I-V characteristics and internal parameter distributions. Preliminary tests were performed with complex filament shapes using the atomistic modeling tools and <u>filament growth</u> under varying electrostatic fields was determined.

NASA Application(s):
This SBIR effort will provide a low-cost, radiation-hardened, non-volatile memory technology tolerant to extreme temperature ranges for all NASA space missions that require storage and processing of large amounts of data. The proposed innovation addresses the NASA technology needs outlined in OCT Technology Area TA11: Modeling, Simulation, Information Technology and Processing Roadmap, in particular, for Computing (Flight Computing, high-performance space-based computing), which requires ultra-reliable, radiation-hardened platforms which have been costly and limited in performance. Other products of immediate impact to NASA include: Computer Aided Design tools for predicting the electrical performance of electronic components and systems across a wide temperature range; and physics-based device models for design and verification of radiation-hardened memory circuits.

Non-NASA Commercial Application(s):
This project will enable significant progress towards the use of memristor-based systems in a wide range of non-NASA aerospace and defense applications that require significant data storage and processing capabilities. The critical question about the combined radiation and temperature tolerance of different memristor technologies will be answered, paving the way for the development of memristor-based non-volatile memory, threshold logic, and reconfigurable architectures (FPGAs) for space applications, such as broadband communication, surveillance, image processing, etc. The improved, physics-based modeling and simulation tools, applicable to both chalcogenide-based and transition-metal-oxide based memristor technologies, will allow designers to perform fast, reliable, and more accurate characterization of memristor-based circuits as a function of various stress conditions (i.e., bias, thermal, and radiation). The simulation and design tools will benefit manufacturers of commercial satellite electronics and avionics, where the memristor is a strong candidate for static RAM, as it combines the advantages of the hard disk (density), RAM (access speed), and flash-based memories (non-volatile).

Name and Address of Principal Investigator:
Ashok Raman
CFD Research Corporation (CFDRC)
701 McMillian Way, Suite D,
Huntsville, AL 35806

Name and Address of Offeror:
CFD Research Corporation (CFDRC)
701 McMillian Way, Suite D,
Huntsville, AL 35806